DESIGN OF MULTIBAND ANTENNAS LOADED WITH ARRAYS OF CSRR AND CIRCULAR HEAD DUMBBELL STRUCTURE

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ABSTRACT: This research focus on two aims, the first one is design a multi-band rectangular Microstrip Patch Antenna with spacious bandwidth by using Complementary Split Ring Resonator (CSRR) beside the Rectangular Ruler Patches (RRPs) and the second is improvement the performance and bandwidth for WiMAX and GPS applications by using Circular Head Dumbbell Structure CHDS beside Circular Ring Patches CRPs. A patch antenna is designed and simulated for 4.66 and 5.61 GHz. Two substrates of FR-4 lossy are utilized with 4.3 dielectric constant, 1.4mm and 0.2mm thickness. The shape used for conventional patch antenna is rectangular with a central feed source. For metamaterial antenna CSRR and CHDS are used. RRPs and CRPs that are used with metamaterial behave like Reactive Impedance surface RIS. The conventional antenna operates at a frequency band of 4.66 GHz and 5.61 GHz, while the designed antenna with CSRR generates four wide band resonant modes at 4.36, 4.7, 5.6 and 5.9 GHz, therefore considered as a multi-use antenna. CHDS appears fixed behavior with all RIS used to confirm its importance in WiMAX and GPS applications. Computer Simulation Technology CST EM simulator is used for this survey.

Keywords: CSRR, RRPs, CHDS, CRPs, CST.

INTRODUCTION

It has become known in wireless communications that microstrip patch antenna has the priority in many usages because of the unique features such simple in manufacturing, tiny size, lower cost than others, light weight, has the ability to integrate with integrated microwave circuits [1]. The first microstrip patch antenna was formed as early as 1970 [2]. The first proposal to design microstrip antenna was by Deschamps in 1953, where gained considerable attention later [3]. There are certain techniques used to feed the microstrip patch antenna [4], like microstrip line feed, probe feed, proximity feed, and aperture feed. The focus on the use of metamaterial in recent time has had a clear effect in improving the microstrip antenna function [2-3]. CSRR is a type of metamaterial that has a negative dielectric constant ε [5], also became very diffuse issue in order to realize a multi-band microstrip antenna [6]-[7]. Speedy development of the wireless communications has made multi-band frequency a necessity for many applications and functions. In addition, the equipment that has this capacity can perform multiple functions at the same time, which may include data transmit, video, audio, radio and so on [8]. In a multi-band antenna, each part operates in a certain range and its gain is below average. The antenna that has circular polarization allows the transmission of steady data without relying on the guidance of the transmitter or receiver, so it is extremely appropriate for communicable equipment and mobile devices. When there are two vertical patterns excited on the antenna in order to output circular polarization which is required for GPS, the broad E-plane patterns are also orthogonally guided in space, supplying broad covering in both main planes. That produces almost a hemispherical pattern, which is perfect for use in GPS, where multiple satellites are in demand to accuracy locate the site [9]. For the purpose of realizing WiMAX and WLAN applications there have been a number of designs that suggest the operation of antenna with dual or multi-band characteristics. Operating frequencies of WLAN are (2.4-2.484) GHz, (5.15-5.35) GHz and (5.725-5.825) GHz and WiMAX (2.5-2.69) GHz, (3.4-3.69) GHz and (5.25-5.85) GHz [10-11].There are many proposals, techniques, and structures adopted to obtain a dual-band or multi-band antenna for WiMAX and WLAN applications such as the ring patch antenna [12-13], the monopole antennas [14], the slot antennas [15]. In this survey array of CSRR and CHDS with RRPs and CRPs as RIS were used in order to achieve multi-band antenna with circular polarization through excitation of two perpendicular polarization modes together at the same time with a 90 ° phase difference depending on [9]. At the end there will also be a study of CHDS behavior and its importance for WiMAX and GPS applications depending on dB.

CONFIGURATION AND DESIGNING PRINCIPLES

The geometrical design of conventional antenna with array 3x3 of CSRR and array of 15x1 RRPs will be shown in Fig1, where

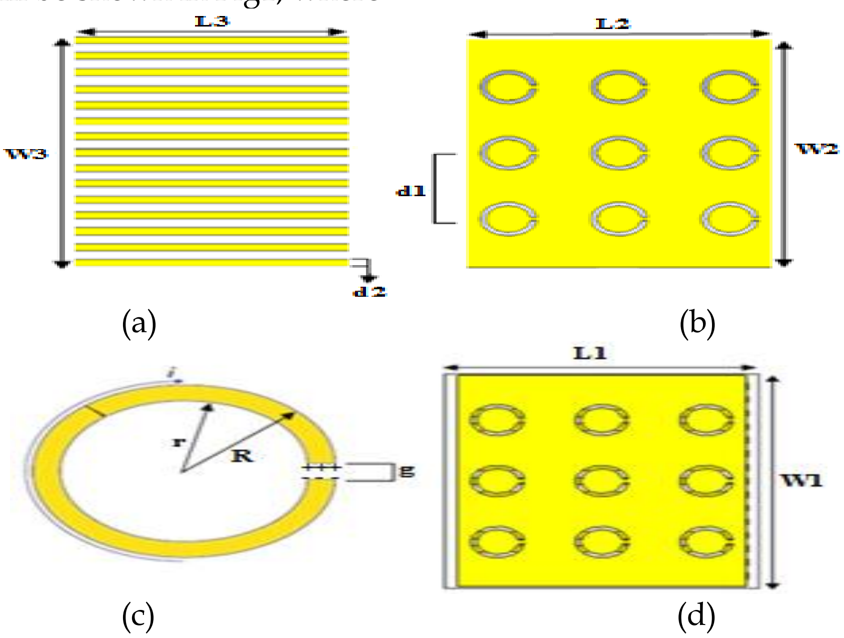


Fig.1. Structural Parts of Multi-Band Antenna: (a) RRPS, (b) CSRR, (c) Single Circular Ring of CSRR, (d) Integrated Antenna.

For CSRR the average loop length is:

$$L = 2\pi \times ((r + R)/2) - g$$

Frequency calculates by:

f = (C/(2L√ε)) Hz
Resonant frequency:
fo = (1/(2π√LC)) Hz
Where L&C represent the inductance and capacitance

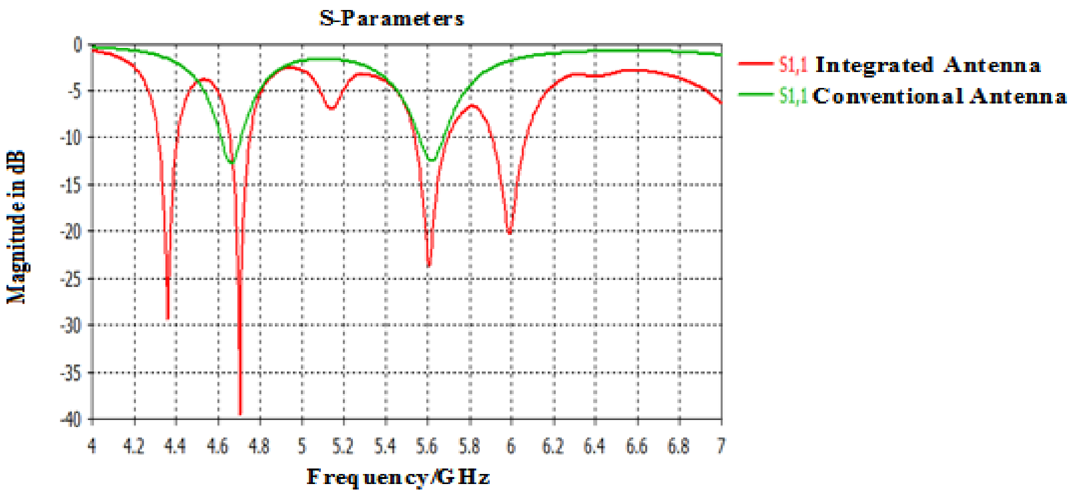


Fig.2. Comparison of Conventional and Multi-Band Antennas.

The effect of RRPs and CSRR metamaterial was positive, the simulation results show that the integrated antenna generated four bands with high return losses, So that gives the antenna a multi-band characteristics compared with dual-band conventional which has poor return loss. Also note that the frequency shift is very little, so that means the coupling between the complementary split rings is very high.

Table1. Dimensions and Parameters of Quad-Band Antenna.

feeder	coaxial feed
Material of Substrate	FR-4 (Lossy)
Material of Patch	Copper (pure)
Material of RRPs	Copper (pure)
Effective dielectric constant	4.3
L1	27 mm
W1	31.7 mm
L2	24.8 mm
W2	31.2 mm
distance between rings d1	9mm
d2	1mm
g	0.5mm
R	2.3mm
r	1.85mm
L3	25mm
W3	29mm

substrate thickness	1.4 mm and 0.2 mm
patch thickness	0.02 mm
RRPs thickness	0.017mm
ground thickness t	0.017 mm

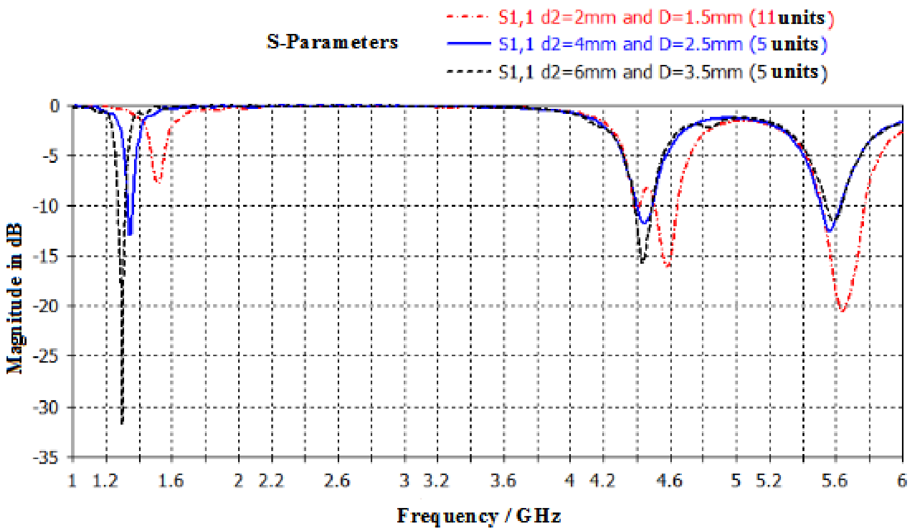
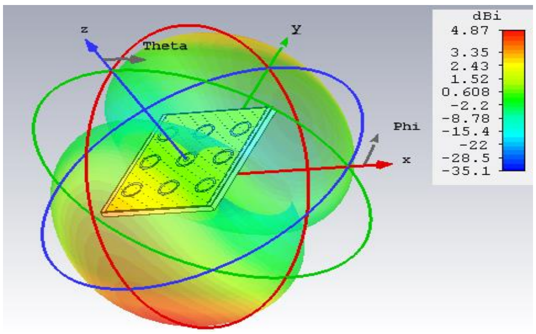
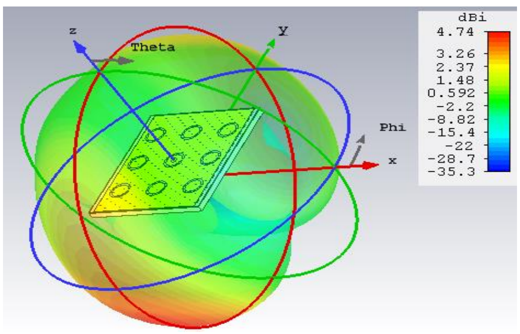


Fig.3. Return Loss at Variable Width d2, Variable Distance between Units D and Variable Number of Units.

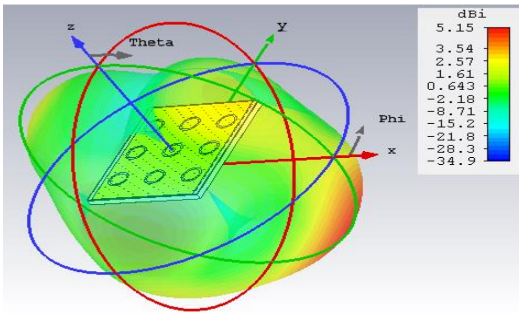
Figure 3 Shows that by increasing the width and distance between RRPs, the return loss of WiMAX band will decrease and return loss of GPS band increase, that almost depend on the orthogonal patterns [9]. Increase the width and distance between RRPs effected on the coupling values between complementary split rings which led to shift the resonant frequencies. So, the purity of vertical polarization created by the excited metamaterial and RRPs will be affected. Although the possibility of use in the GPS applications, but that leads to several disadvantages including the weakening of WiMAX functions and other operating bands, also reduce the efficiency.



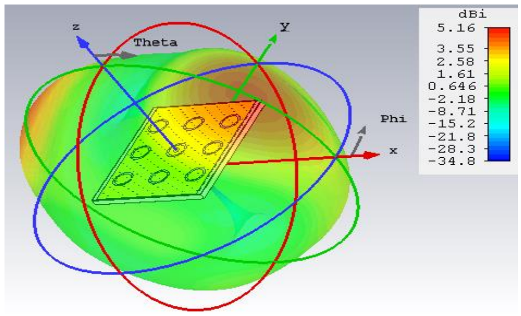
(a)



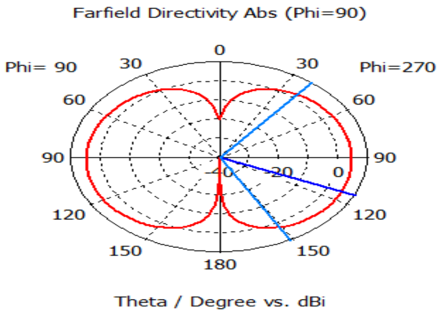
(b)



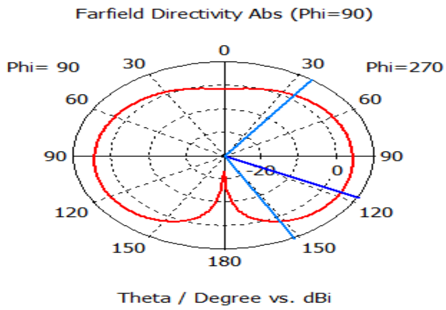
(c)



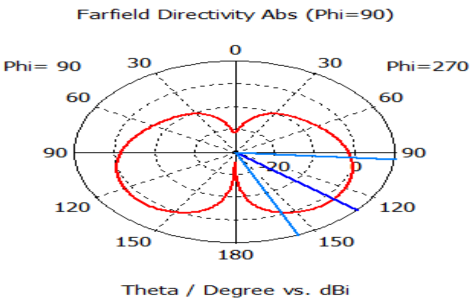
(d)



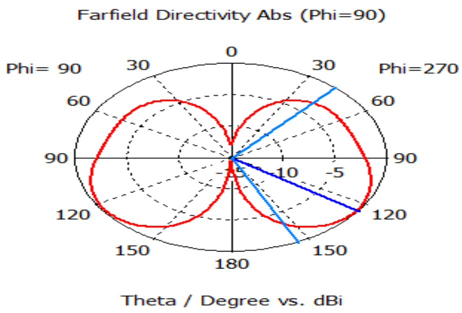
(e)



(f)



(g)



(h)

Fig.4. Radiation Pattern (RP) and Polar Plot (PP) of Multi-Band Antenna (a) RP at 4.36 GHz (b) RP at 4.7 GHz (c) RP at 5.6 GHz (d) RP at 5.99 GHz (e) PP at 4.36 GHz (f) PP at 4.7 GHz (g) PP at 5.6 GHz (h) PP at 5.99 GHz.

SIMULATION AND RESULTS

Figure 2 shows the return loss simulation of multi-band antenna compared with conventional. The use of RRPs and CSRs metamaterial give better results by increasing the number of bandwidth and enhancing the return loss. New antenna operates at (4.36 GHz, 4.7 GHz, 5.6 GHz and 5.99 GHz) with return loss (-29.4dB, -39.4dB, -23.6dB and -20dB) respectively. The operating bands of antenna are 91

MHz at 4.36 GHz, 95 MHz at 4.7 GHz, 158 MHz at 5.6 GHz and 162 MHz at 5.99 GHz. Compared with conventional which operates at 4.66 GHz and 5.616 GHz with return loss -12.7dB, -12.5dB only and 95, 114 MHz bandwidth. 3D radiation pattern and polar plot for quad-band antenna were simulated. The simulating results appear in figure 4, where (a), (b), (c), (d) refer to radiation pattern and (e), (f), (g), (h) refer to polar plot. The directivity of antenna is 4.87 dBi, 4.74 dBi, 5.15 dBi and 5.16 dBi at 4.36 GHz, 4.7 GHz, 5.6 GHz and 5.99 GHz respectively, The beam main lobe direction is 6 degree with beam width 112.7 degree at 4.36 GHz, 3 degree with beam width 116.5 degree at 4.7 GHz, 10 degree with beam width 62 degree at 5.6 GHz and 5 degree with beam width 112.8 degree at 5.99 GHz.

STUDY THE BEHAVIOR OF CHDSs ON SEVERAL TYPE OF RIS

Observed through the simulation results that insertion of Circular Patch CP, RRPs or CRPs with CHDSs shows a dominant and consistent behavior of metamaterial on antenna. Analysis of this behavior would require many tests with several Reactive Impedance Surface RIS that operate at different frequencies. However, the use of CP with CHDSs was very important to understand that behaviour because changing the diameter of CP in each case was given a new frequency with the conventional antenna, On the other hand use of RRPs and CRPs also signifycant to test a different shapes with different dimensions.

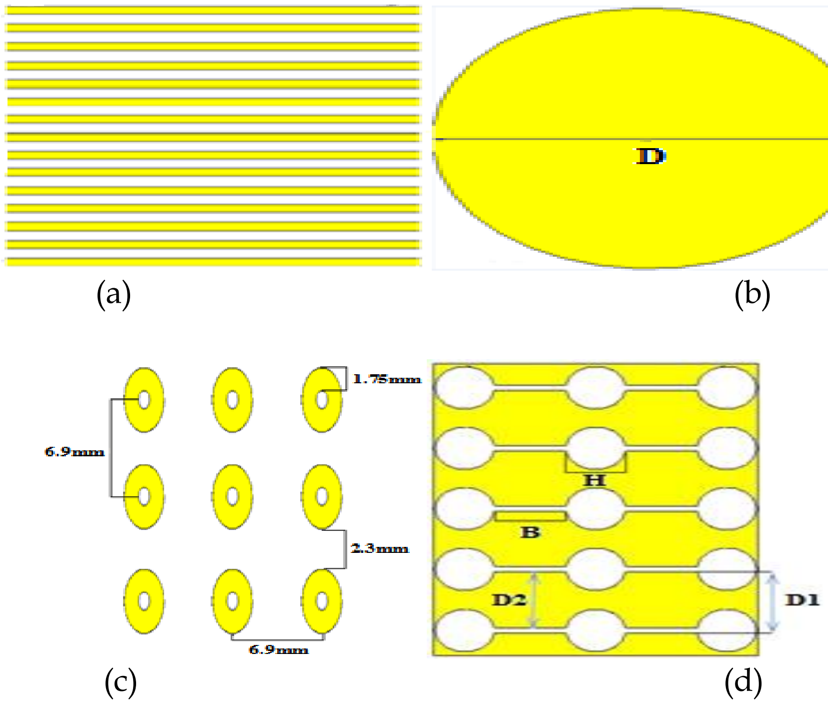
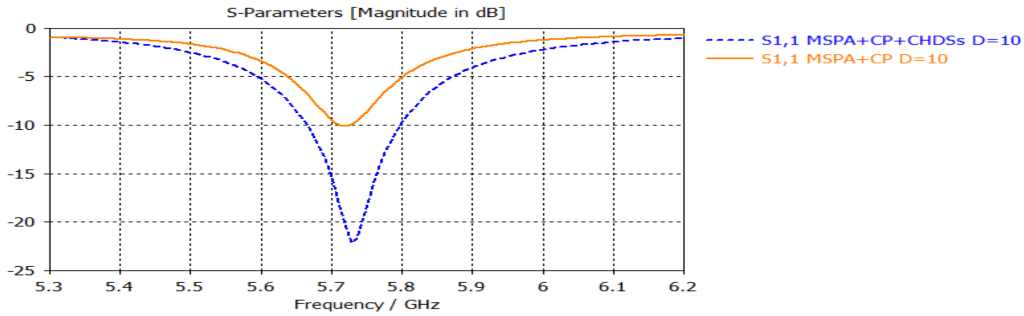
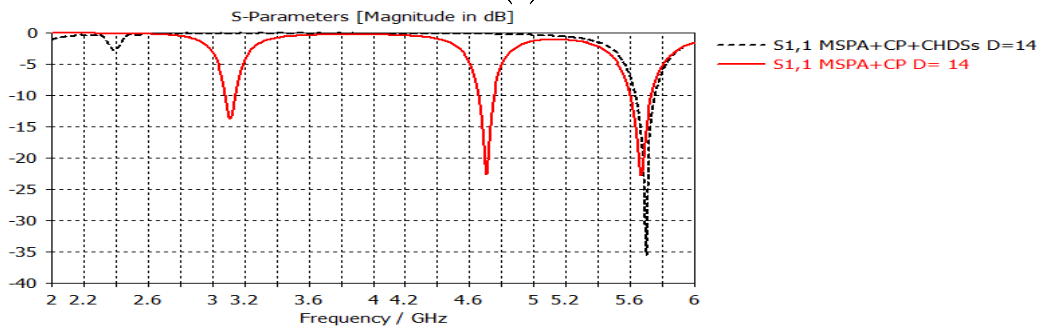


Fig.5. Shows the Shapes of RIS used with CHDS which are (a) Rectangular Ruler Patches, (b) Copper Circular Patch with Various Radius, (c) Circular Ring Patches, (d) Circular Head Dumbbel Structure with Dimensions of D1= 6.5mm, D2=6.0mm, B=5.43mm, H=4.57mm, Redius=2.3mm.



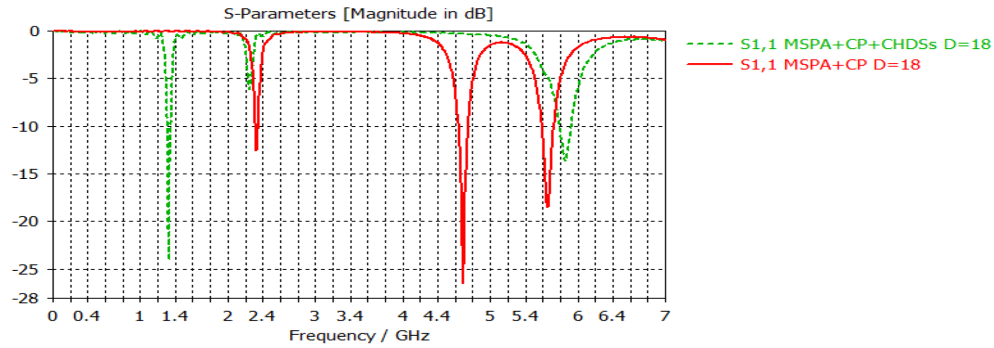
S-Parameters [Magnitude in dB]
0
-5
-10
-15
-20
-25
5.3 5.4 5.5 5.6 5.7 5.8 5.9 6 6.1 6.2
Frequency / GHz
S1,1 MSPA+CP+CHDSs D=10
S1,1 MSPA+CP D=10

(a)



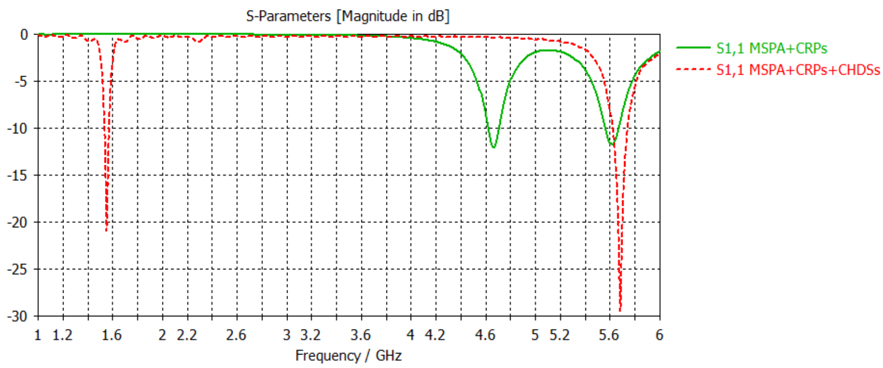
S-Parameters [Magnitude in dB]
0
-5
-10
-15
-20
-25
-30
-35
-40
2 2.2 2.6 3 3.2 3.6 4 4.2 4.6 5 5.2 5.6 6
Frequency / GHz
S1,1 MSPA+CP+CHDSs D=14
S1,1 MSPA+CP D= 14

(b)



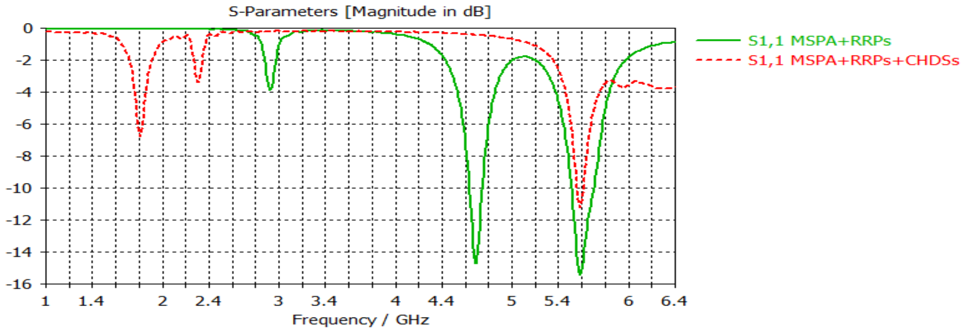
S-Parameters [Magnitude in dB]
0
-5
-10
-15
-20
-25
-28
0 0.4 1 1.4 2 2.4 3 3.4 4 4.4 5 5.4 6 6.4 7
Frequency / GHz
S1,1 MSPA+CP+CHDSs D=18
S1,1 MSPA+CP D=18

(c)



S-Parameters [Magnitude in dB]
0
-5
-10
-15
-20
-25
-30
1 1.2 1.6 2 2.2 2.6 3 3.2 3.6 4 4.2 4.6 5 5.2 5.6 6
Frequency / GHz
S1,1 MSPA+CRPs
S1,1 MSPA+CRPs+CHDSs

(d)



(e)

Fig.6. Shows Comparison between the use of RIS alone with the Conventional Antenna and the Effect of CHDS Behavior when added with. (a) CP at Diameter of 10mm, (b) CP at Diameter of 14mm, (c) CP at Diameter of 18mm, (d) CRPs, (e) RRPs.

Table2. Characteristics of RIS Effect on Conventional Antenna.

Parameter	RRPs antenna at 4.68 GHz	CRPs antenna at 4.66 GHz	CP antenna at 4.69 GHz D=16mm
Return loss dB	-14.7	-12	-33
Bandwidth MHz	109	89	106
Directivity dBi	5.21	5.16	5.31
Parameter	RRPs antenna at 5.58 GHz	CRPs antenna at 5.61 GHz	CP antenna at 5.65 GHz D=16mm
Return loss dB	-15.4	-11.7	-19.7
Bandwidth MHz	192	103	135
Directivity dBi	5.45	5.34	5.26
Parameter	RRPs antenna at 2.65 GHz	CRPs antenna at 2.65 GHz	CP antenna at 2.65 GHz D=16mm
Return loss dB	-	-	-25.9
Bandwidth MHz	-	-	57
Directivity dBi	-	-	2.23

From figure 6 and table 2, the behavior of the CHDS array was concluded. The study depends on the return loss of all RIS elements where observed that behavior of CHDS was consistent with all elements.

CHDS WITH CP

1. CP diameter=10mm

As previously mentioned that the return loss of conventional antenna is -12.2dB at 4.66 GHz and -12.1dB at 5.61 GHz. Return loss of CP at D=10mm without CHDS is less than conventional just -10.1dB at 5.7 GHz. Adding CHDS increased the return loss to -22dB, also enhanced the bandwidth from 12MHz to132MHz.

2. CP diameter =14mm

Return loss of CP at D=14mm without CHDS is higher than conventional and has three bands, -22.8dB at 5.66 GHz, -22.6dB at 4.7 GHz and -13.8dB at 3.1GHz with good bandwidth of 132MHz, 95MHz and 62MHz respectively. Adding CHDS removed the band of 4.7 GHz and 3.1 GHz with raise in return loss of 5.6 GHz to -35.5dB and reducing the bandwidth.

3. CP diameter=18mm

Return loss of CP at D=18mm without CHDS has three bands, -18.46dB at 5.65 GHz, -26.5dB at 4.68 GHz and -12.5dB at 2.3 GHz with good bandwidth of 135 MHz, 110 MHz and 32 MHz respectively. Adding CHDS removed the band of 4.68 GHz with decrease in return loss of 5.6 GHz to -13.6dB and shift the band of 2.3 GHz to 1.3 GHz with high return loss of -24dB and 37 MHz bandwidth.

CHDS WITH CRPs

Return loss of CRPs without CHDS is less than conventional of -12dB at 4.66 GHz and -11.7dB at 5.61 GHz with less bandwidth of 89MHz and 103MHz respectively. Adding CHDS improved the return loss and bandwidth to -28.2dB and 123MHz at 5.6 GHz and shifted the band of 4.66 GHz to 1.55 GHz with increase in return loss of -18.8 dB.

CHDS WITH RRPs

Return loss of RRPs without CHDS is -14.7dB at 4.68 GHz and -15.4dB at 5.58 GHz with bandwidth of 109MHz and 192MHz respectively. Adding CHDS reduced the return loss and bandwidth to -11.16dB and 52MHz at 5.58 GHz and removed the band of 4.68 GHz.

Conclude from that, CHDS metamaterial deals with RIS elements according to their effect on the conventional antenna as following, If the return loss of the RIS is less than -10, but has a negative impact on the conventional antenna by reducing its return loss, the CHDS will increase the return loss and bandwidth of WiMAX frequencies which between (5.25-5.85) GHz [12-13] and shifts 4, 3, 2 GHz frequencies band to the GPS band. If the return loss of the RIS is between (-10dB to -20dB) and has higher return loss than conventional, the CHDS will reduce the return loss and bandwidth of WiMAX frequencies that between (5.25-5.85) GHz and removes 4, 3, 2 GHz frequencies band. If the return loss of the RIS is less than -20 and higher than conventional, the CHDS will increase the return loss and decreases bandwidth of

WiMAX frequencies which between (5.25-5.85) GHz and removes 4, 3, 2 GHz frequencies band.

CONCLUSION

Two types of metamaterial were used, both have generated circular polarization which produced by orthogonal of excited radial patterns with 90 degree [9], CSRR has used with RRPs to generate quad-band antenna for several applications, CHDS has used with several RIS and showed the same behavior, thus It can be used in WiMAX and GPS applications to enhance the received signals. Changing CHDS dimensions make it lose its properties.

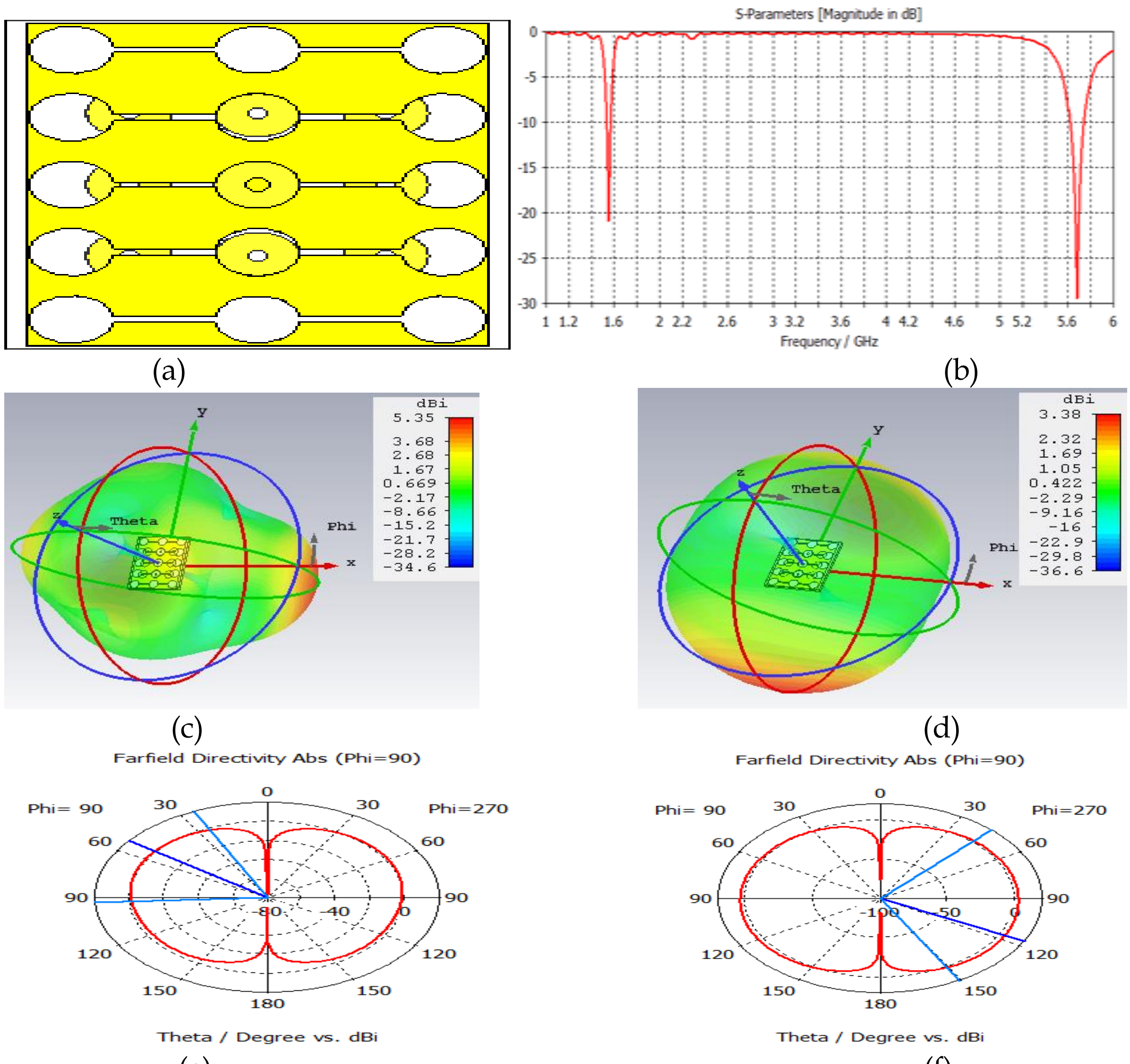


Fig.7. Return Loss, Radiation Pattern (RP) and Polar Plot (PP) of Dual-Band Antenna by using CHDS plus CRPs (a) Integrated Antenna, (b) Return Loss, (c) RP at 5.68 GHz, (d) RP at 1.55 GHz, (e) PP at 5.68 GHz, (f) PP at 1.55 GHz. 3D Radiation Pattern and Polar Plot for Complementary Antenna were simulated.

The simulating results appear in figure 4.12, where (a), (b) refer to Radiation Pattern and (c), (d) refer to Polar Plot. The Directivity of Antenna is 5.35 dBi and 3.38 dBi at 5.68 GHz and 1.55 GHz respectively. The Beam Main Lobe Direction is 7 degree with Beam Width 68 degree at 5.68 GHz and 3 degree with Beam Width 107.4 degree at 1.55 GHz.

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